SINTERING AS PRACTICED

IN THE UNITED STATES,

by

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FOREWORD

This report presents some of the facts about sintering as practiced in the United States both in the past and at the present time.

The history, production data, applicability, and some of the physical-chemical relationships of the sintering process are discussed. An example of current commercial sintering practice is also included.

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I. INTRODUCTION

Sinter may be roughly defined as a porous agglomerate of fine mineral particles which were fused together by the propogation of internal combustion and oxidation through the charge which contained them, this propogation being effected by means of strong air currents forced through the charge in a sintering machine.

The design of the sintering plant and the design of a sintering machine should not be confused.[10] Satisfactory over-all sintering practice is dependent upon facilities for unloading, storing, screening, and mixing raw material; upon adequate tracks, storage space, and rolling stock for handling the sinter and also coarse ore if screening is involved; and upon sintering machine auxiliaries such as conveyors, pug mills, ignition furnaces, dust collectors, fans and control instruments.[10]

Unless the sintering plant is properly designed, the best quality of sinter and the largest output from any combination of raw materials cannot be expected no matter what the design of the sintering machine may be.[10] With this fact in mind, the entire sintering plant has been given some consideration; however, the sintering machine has still received the major emphasis in this report.

II. THE DEVELOPMENT OF SINTERING MACHINE CAPACITY IN THE UNITED STATES

The first sintering plant built for sintering iron-bearing materials in this country was built in 1911 at Birdsboro, Pennsylvania. This sintering plant had one machine having 89 square feet of suction area, and it turned out a total of 125 tons of sinter produced from flue dust. In the following year three more plants were built having a producing area of 350 square feet. The total producing area of sintering plants had grown to 8900 square feet by 1920, and by 1930 the total had expanded to 23,567 square feet. The next nine years were relatively inactive, for only 4360 square feet of suction area were added during this time; many machines were dismantled during the same period. The year 1940 found approximately 20,000 square feet of sinter-producing area available in the United States, and this could produce between 3,000,000 and 4,000,000 tons of sinter a year.[12]

World War II caused an enormous expansion of sintering facilities in this country as is evidenced by production figures for those years.

<u>Sintering Capacity of the United States</u>

January 1, 1940	3,000,000 to 4,000,000 net tons[12]
January 1, 1942	16,371,000 net tons
January 1, 1943	18,199,000 net tons
January 1, 1944	24,267,000 net tons
January 1, 1945	26,195,000 net tons (on completion of the expansion program)[19]

From 1911 to 1940 about 67,000,000 tons of iron-ore sinter were produced in the United States; 35,000,000 tons of this total (53 per cent) were produced from sintered flue dust; 28,150,000 tons (42 per cent) were produced from concentrates and ore; and 3,350,000 tons (5 per cent) were produced from pyrites (FeS_2).[12]

As much or more sinter was produced during the years from 1940 to 1946 than was produced during the years 1911 to 1940. This was due to the increase of <u>active</u> sintering capacity from approximately 4,000,000 to 26,000,000 net tons per year.

Until 1917 all of the continuous sintering machines were 25 feet 6 inches long and had an area of 89 square feet. The producing areas became progressively larger until in 1931 a machine with 768 square feet of active area was built. Although the producing areas of these machines have been constantly enlarged since that time, the average size of the 50 continuous sinterers operating in 1940 was only 260 square feet.[12]

The pans used in the intermittent system have grown with the years from a 7' x 12' size to about 10' x 30' size used today.

Thus the size of sintering units in this country have grown from 1911 with about 89 square feet of suction area, producing 125 tons in 24 hours; to units of 765 square feet suction area producing over 2000 tons in 24 hours. The Youngstown Sheet and Tube Company has a plant which produces 2400 tons of sinter in 24 hours,[21] and the Republic Steel Corporation has several plants that can equal this production.[8]

III. APPLICABILITY OF SINTERING

1. Sintering Material Sources

   A. Blast Furnace Flue Dust

   B. Mixtures of ore, roll scale, and flue dust.

   C. Ores of such fineness that the ratio of metallic iron charged to the iron smelted becomes a doubtful element which results in an abnormal fuel ratio in the furnace.

   D. Ores of such high sulphur content as to influence sulphur content of the iron.

   E. Ores of such high combined water content that the expulsion of combined water in the hot zones causes unnecessary fuel consumption.

F. Ore of such large size that crushing and sizing is necessary in order to get uniform distribution in the furnace.

G. Natural ores of such high moisture and combined-water content, yet sufficiently low in gangue, that they are in a prohibitively penalized class of ore price schedules.

H. Ores carrying such high moisture and combined-water content and of such location that prohibitive freight costs are incurred in their delivery to the consumer.

I. Carbonate ores whose CO_2 content puts prohibitive freight charges on iron content to the consumer (not commercially applicable to date).

J. Ore which must be ground to remove gangue and undesirable constitutents in order to raise the grade and in which grinding produces fines which cannot be used in the furnace.

K. Ore which must be ground very fine in order to remove the iron from some other valuable mineral and in which flotation may be used to make the separation (not common).[11]

2. Commercial Applications

In considering the treatment of any ores or iron-bearing materials having any of the above depreciative qualities, it is well to bear in mind that sintering corrects them all in a single simultaneous operation. Complete agglomeration, calcination, desulphurization, and dehydration are performed on any iron-bearing material by a single step, the process of sintering.[12]

In present practice approximately 53 per cent of the sinter produced is made from flue dust, and about 42 per cent of it is made from ores and their concentrates.[12] Therefore, these two applications will receive the largest consideration in the following discussion of sintering material sources listed in part 1 of this topic.

Type 1-A. Reliable determinations have shown that the daily flue dust product collected for a furnace producing 600 tons of pig iron per day is about 80 tons of flue dust.[12] This flue dust is classed as primary and secondary dust. The primary dust is that caught in the primary dust catcher, while the secondary dust is that separated from the gases after they have passed the primary dust catcher. Only a small percentage of the secondary dust is being obtained today, for the dust is so fine that it is difficult to recover.

In the beginning, steel companies stored their flue dust in huge stockpiles, for they had no commercially applicable method with which to treat it. However, sintering plants were built later to reduce these stockpiles; thus sintering was applied to iron-bearing materials which were practically worthless until claimed by such treatment. In such cases the low valuation of the raw material provided a wide margin of profit for the sintering operation, for all flue dust can be sintered to a physical state superior to the best natural ores at a fraction of the unit cost of equivalent ore.[12]

Having a sintering plant and sintering the current production of flue dust with the stockpile dust gives a still greater sintering profit because, in addition to the net gain on ore value reclaimed, it saves the cost items in pig iron production of transportation to stockpile, and unloading and loading therefrom. Flue dust sent directly from the furnace to the sinter plant eliminates these flue-dust handling costs.[12]

Type 1-B. The sintering of ore was a gradual development. Most flue dust contains much carbon which is blown from the furnace with the fine ore particles, and this carbon is usually in excess of the amount required as fuel for sintering the flue dust; this excess carbon slows the sintering rate. Only in a few cases is flue dust which does not contain excess carbon found. This excess of carbon over sintering requirements is available for sintering other iron-bearing materials which are available. The increased production of a sintering plant by this means is usually that of the quantity of ore sinterable with the excess of carbon over that required to sinter the flue dust.[12]

The cost of sintering the added ore is nominally that of handling it to and from the sintering plant, since no additional equipment is necessary to treat it. This condition provides additional earning capacity and economies by treating extremely fine ores and naturally undesirable and cheaply available iron-bearing materials.[12]

Type 1-C. Under this class may be noted large deposits on the Mesabi Range, the proportion of fines of which are increasing year by year. It is not economically feasible to sinter these ores at the mine unless the moisture content is less than 12 per cent, for the costs of sintering fuel and power are comparatively high in Minnesota.[4, 12]

It may be profitable to sinter fine concentrates as produced at the Mesabi Range, however, since the handling equipment at the concentrator will perform the same function required of it in a separate sintering plant. This can be done only if fuel costs are reduced in this area, for the present fuel prices make sintering costs prohibitive; this is due to the fact that this area has no local source of sintering fuel, and this commodity must be shipped or piped into the district.

Type 1-D. Ores of this high a sulphur content are subject to a depreciation of sales value. This type of ore is subjected to complete de-sulphurization by sintering. This is true of both hematites and magnetites regardless of whether the sulphur is present in sulphate or sulphide form. If the ore is hard or massive in character, it is necessary to crush it down to 3/8 or 1/4 inch in order to get sufficiently complete de-sulphurization by sintering.

The fact that a sulphide bearing ore requires less fuel to sinter than does a non-sulphide ore renders it more attractive from a cost standpoint, since the cost of fuel is one of the main sintering costs.

High-sulphur magnetic ores have and are being treated in large tonnages in the eastern part of the United States, and de-sulphurization of such ferrous by-products as pyrite cinder has been widely practiced both in the United States and abroad (especially in Spain and Italy).

Types 1-G, 1-H, and 1-D. Ores in these classes come under the same general group. There are large deposits of such ores on the Mesabi and Cuyuna Ranges.[12] The Mayari ores of Cuba are also typical of this class. These ores are subject to great beneficiation by sintering, and millions of tons lie in the ground, or are thrown on the dump, which by sintering may be converted into the highest grades on the market.

Type 1-I. The CO_2 content of these siderite ores dilutes the iron content sufficiently to make the cost of shipping them prohibitive. The carbonate ores are further undesirable on account of their deflagration tendency in the furnace and the additional fuel consumption. By crushing such ores down to 1/2 inch size and sintering, they can be made highly desirable and subject to lowest possible freight cost to the consumer. (Commercially this has not been economically feasible.)

IV. A GENERAL OUTLINE OF SINTERING PLANT OPERATION

Ore which is to be sintered is kept in storage until used. From the ore stockpile the ore is conveyed to the screening plant where any material too large for sintering is rejected, while the fines are conveyed to the sintering plant storage bins. The sintering plant storage bins also hold flue dust and coke breeze. Ore fines, flue dust, and coke breeze are fed on to a conveyor belt, in the correct proportions, and this belt delivers them to a pug mill. These constituents of the sintering charge are mixed with the proper amount of water in the pug mill, and the pug mill discharges the mix into another machine which in turn delivers the sintering charge to the sintering machine in the properly fluffed condition (made as porous as possible). The ignition furnaces ignite the charge, and the sintering is effected with the aid of the huge down-draft suction fans used. The discharged sinter is air or water-cooled to obtain the desired physical properties, and the sinter is ready for blast furnace use. However, some sintering plants screen their sinter prior to its use in the blast furnace; this is done to make a more uniformly sized charge possible.

V. SINTERING MACHINE TYPES.

1. General Discussion

During World War I three types of sintering machines were operated in the country: the Dwight-Lloyd, the Greenawalt, and the Plock. Today the Dwight-Lloyd is the leading machine in the sintering field, the

Greenawalt machine is fast disappearing, the remaining ones being found largely in the Minnesota iron district, and the Plöck machine is extinct.

The rotary sintering kiln, similar to a regular cement kiln, is growing in popularity for use in sintering iron ores, year by year, as improvements are made in its operation and design features. It appears that more and more of this type of sintering machine will come into use in the future. Another new type of sintering machine has been introduced by Agnew,[17] and it will be discussed in a succeeding paragraph.

All of these sintering machines, excepting the rotary kiln type, are based on the same principles of operation, which are as follows: down-draft suction, ignition on top of the charge, and self-propogation of the sintering action down through the charge. The sintering machines vary in their method of charge handling and ejection, the Dwight-Lloyd and the Agnew machines being of the continuous charging and dumping types, while the Greenawalt is an intermittent charging and dumping type. These machines will be discussed more fully in later paragraphs.

2. The Dwight-Lloyd Sintering Machine

The Dwight-Lloyd machine is of the continuous down-draft type. It has a strong frame of structural steel supporting two large, heavy sprockets, and a steel track or guide. An endless system of pallets or pans, with perforated bottoms, travels on the sprockets and is driven by them.[1] The pallets hold the charge of ore (or other iron-bearing material) flux, and fuel during the roasting process. Each of the pallets runs on four wheels on the track mentioned above except over the suction box, where they pass over a flat plate in order to make a joint which is as nearly airtight as possible. The whole pallet train is driven by the sprocket, the pallets being pushed along the track by those that follow until they reach the end when, guided by the curved irons there, they slide down the guides and strike the preceeding pallet (a space of about 24 inches is provided).[1] This impact jars the sinter cake loose and it falls into a conveyor or waiting car, while the empty pallets return down the lower inclined track by gravity.

These pallets, made of malleable iron, are one of the defects of the machine, for they tend to become blinded by fine sintering material and to warp because of the heat generated. Also, lubricating difficulties have been experienced by some operators of these machines. Underneath the train of pallets is a suction box which is connected to produce a down-draft through the perforated pallet bottoms and the ore charge. (This box also acts as a dust catcher.) Mounted above and near the feed end of the apparatus is an ignition box, fired with gas or oil fuel, which furnishes the heat to start the sintering process. The charge enters the machine from a mixer and hopper located above it, and an adjustable leveling gate levels off the charge to insure a tight seal between the charge and the sides of the pallet.

The standard Dwight-Lloyd machine now in use is 22 feet long and 42 inches wide, but special machines up to 80 feet in length have been designed for sintering iron-bearing materials.[1, 12]

Material from dust up to particles 1/4 to 1/2 inch in size may be sintered on these machines. The composition of the charge, the suction strength, and the rate of pallet travel are the factors by which the type of sinter produced can be controlled.

The actual sintering process will be discussed later in this paper.

This machine is called the continuous type because of the fact that there are always some pallets being charged with sintering material while other pallets are being emptied of their sinter product.

3. The Greenawalt Sintering Machine

The Greenawalt sinterer is also of the downdraft type, but its mechanism varies markedly from the Dwight-Lloyd machine.

The Greenawalt machine is essentially a huge, rectangular pan which is mounted on trunnions for dumping purposes. The pan is filled with charge in the upright position, and a strong suction is applied to the charge through the trunnions. The charge is ignited on top by means of an ignition hood which is moved into position over the pan. About one minute of sintering time is required for each inch of charge to be sintered in the pan.

The present-day Greenawalt pan is about 30 feet by 17 feet in dimension.

This machine is called the intermittent type, for it is charged and dumped only at the beginning and ending (respectively) of the actual sintering process.

4. The Rotary Sintering Kiln

Operating difficulties are encountered when a plain rotary kiln is used for sintering or nodulizing iron ore fines or blast furnace dust; these difficulties are caused primarily by the formation of excessive coatings or "rings" near the discharge end of the kiln due to the adherence of the sticky material to the fire-brick lining. This coating reaches such a proportion in a few days that it prevents the proper passage of material being sintered. Operating records show that it is necessary to shut down to remove rings after five to seven days' operation; two or three days' shutdown are required to clean the kiln, so it is apparent that this type of operation is not very profitable.

In 1941 a new type (design) of rotary kiln was put into operation.

This kiln, due to its shape and means for adjustment of the firing equipment, has a relatively short sintering zone; the sintering zone is about 18 feet measured from the discharge end of the kiln.

The object of the special design of the kiln is to concentrate the sintering in a relatively short zone in which excessive coating on the lining may be removed easily and regularly without disturbing the kiln operation. This is accomplished by means of a powerful, water-cooled boring bar equipped with a cutter and mounted on a heavy carriage. It operates in somewhat the same manner as a very large lathe; the carriage is power driven and operates on tracks on the burner floor.

When sintering iron ore, the boring apparatus is normally used once or twice during each eight-hour shift, and the boring operation requires only ten to fifteen minutes; the kiln continues rotating during the boring operation.

A specially designed pan conveyor operating in a long firebrick-lined tunnel is normally used to cool the sinter, but other types of cooling equipment are available.

In general, the modern rotary sintering kiln has the following advantages:[16]

(1) Porous, strong sinter with a minimum of fines. (No screening)

(2) Flexibility in operation. No specific requirements as to moisture, carbon, fineness or chemical composition of kiln feed. (Flame adjustment compensates for variations.)

(3) Low fuel consumption and reduced sintering temperatures. Any fuel available at low cost may be used for sintering.

(4) Low power consumption due to absence of high vacuum exhausters.

(5) Low labor cost. Ordinarily only three operators per shift are required.

(6) Low dust losses. Kiln operation is practically dust free; this is desirable both economically and from a labor standpoint.

(7) Low maintenance cost. The machinery is very rugged.

However, the primary cost of rotary kiln equipment is fairly high.

Sixteen rotary sintering kilns had been installed in Europe prior to the war, and some of these have capacities of 500 tons of sinter per day. These kilns could be designed for much larger capacities.[16]

5. The Agnew Sintering Machine

Charles E. Agnew designed a sintering machine in 1941 which was called a superior design[17] by the magazine, Blast Furnace and Steel Plant.

The overall design of the Agnew machine is similar to that of the Dwight-Lloyd type in that it consists of an endless train of movable grate bar pallets.[17] The Agnew pallet, however, is wheelless and the pallet train is propelled by a rack cast in the pallet. The pallets move on a stationary roller trackway with curved sections of roller trackway at the ends of the machine.

The advantages of a roller trackway over wheels mounted on the pallet are said to lie in the ease of lubrication of the roller trackway, and in the comparative ease of pallet replacement on the Agnew machine.

Many other economy claims are made for the Agnew Sintering Machine, but since I could find no material discussing the setting up or operation of a sintering plant using these machines, a comparison is not possible.

VI. FACTORS WHICH VARY SINTERING MACHINE OPERATION

1. A General Description of the Sintering Process

In the sintering process a quantity of fine ore, or a quantity of flue dust, or a mixture of both, together with a small amount of coal or other fuel, is first moistened with water; then the mixture is spread in a layer on the grates of a sintering machine. The top of this layer, or bed, is then ignited and air is drawn down through it so that combustion is carried on down through the bed. During this process a high temperature zone, the actual sintering, travels through the bed and when it reaches the grates at the bottom of the process is completed.[12]

In general, sintering may be called an oxidizing or burning process; therefore, the volume of air passing through the charge is the most important factor to be considered. The air must pass through with sufficient rapidity to produce the necessary heat, and if its rate of flow is sufficiently rapid combustion will take place with sufficient intensity to produce a sintering temperature; if the flow of air is inadequate the burning action will be too slow to generate sufficient heat to form sinter.[2]

The first sintering objective is to pass air through the charge in sufficient volume to produce a sintering temperature in the mass, and this is greatly influenced by two important factors: (1) the porosity of the charge itself and (2) the pressure applied to force the air current through the pores of the charge by means of suction.

2. Porosity of the Sintering Charge

The porosity of the charge is influenced by three important factors: (1) moisture, and (2) returning part of the sintered charge as "returned fines," and (3) mixing the charge.

A. <u>Moisture</u>. The porosity of fine, dry ore to gas flow is so small that it becomes impracticable to pass air through the charge in sufficient volume to produce a sintering temperature. Fortunately, however, if water is added to this charge and is mixed thoroughly with it, the porosity of the charge is greatly increased. The porosity of the charge will increase progressively with increasing water content until a maximum is reached; the continuance of water addition after the maximum has been reached will progressively decrease the porosity until at last it will be completely destroyed. The amount of moisture used to obtain maximum porosity is usually the best percentage of water to use in preparing the charge for sintering. In actual practice this depends upon the character of the ore and may vary from five to twelve per cent, not including combined moisture. Magnetic ores require the least and clayey ores the most moisture to produce the best physical condition for sintering.[2]

The character of the sinter can be slightly influenced by the moisture content of the charge; the drier charges tend to produce a more fragile sinter, while the wetter charges produce a stronger and denser sinter. I do not know the reasons for the effect of the moisture upon the physical structure of the sinter, nor did I find them in my readings. High moisture in the charge decreases its combustibility and increases combustion difficulties.[13]

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B. <u>Returning Part of Previously Sintered Charge in Form of "Returned Fines."</u> It is impracticable to produce 100 per cent sinter in one operation, so the sintered charge is passed over a screen and all the fine material below a fixed size is returned and resintered. The size of the screen-grating openings may vary from 1/4 inch to 3/4 inch, and the amount returned may vary from 20 per cent to as much as 50 per cent; however, in the intermittent system this is rarely more than 25 per cent. Much of the returned material has already been sintered, so the addition of it to the charge greatly increases the porosity and sintering qualities of the charge, thereby increasing the capacity of the sintering unit. It improves the sintering charge just as it improves the blast furnace charge. This practice, however, has the disadvantage of double sintering; this requires additional fuel which adds considerably to the cost of sintering low-grade ores.[2]

This resintering of part of the charge that has been partially sintered previously and which fuses far more readily than the original charge strongly tends to the formation of the undesirable iron silicates in the finished sinter, so that the modern tendency is to reduce the returns to a minimum. This practice gives a less porous sintering charge, but is is deemed necessary to prevent iron-silicate formation.

C. Preparing the Charge to Consist of a Mixture of Materials. This method of increasing the pprosity of the sintering charge is very desirable whenever it is applicable; it can be used to mix fine ores with flue dust, roll scale, etc. It is also advantageous to mix fine magnetic concentrate with coarser ores in the preparation of the sintering charge. This method of increasing the porosity of the charge has its limitations in the amounts of materials available for this purpose.[13]

3. Thickness of the Charge

There is a definite resistance to the flow of air through a charge; the amount of air that will flow through a charge is proportional to the thickness of the charge and to the suction applied to the lower part of the charge. The thickness of the charge treated is very important. Economically a thick charge has many advantages over a thin layer. The cost of charging and igniting a thick layer is no more than for a thin layer, and it also has the advantage of requiring less sintering fuel per weight of charge ignited. In plants using the intermittent system, the depth of charge varies from 7 inches with fine magnetic concentrate to 18 inches with the fines of a hematite ore below 3/8 inch particle diameter.

The time of sintering--the time required for the sintering zone to travel from the top surface of the charge to the grate--also is a factor affecting the thickness of charge used. Experience has shown that eighteen minutes should be the maximum sintering time allowed, for if the charge requires more time than this to sinter the portion of the charge near the grate dries out and greatly slows up the travel of the sintering zone through the charge. The sintering zone should move through the charge at the rate of about 1 inch per minute for charges up to 18 inches deep to prevent drying out of the charge and the resulting slower sintering rate and lower sinter production.

The thickness of the charge is also dependent upon the suction available. Tests made by A. K. Walter [2] showed that by increasing the suction from 17 inches of water to 40 inches, the capacity of the sintering machine used was increased 140 per cent. By increasing the suction from 17 inches to 40 inches and at the same time depositing the charge into the sintering apparatus with the greatest possible amount of uniformity and porosity, the sintering capacity was increased 194 per cent. Every inch of suction increase increased the sintering capacity 6 per cent in the first case.[2] Present-day applications of high-suction apparatus have demonstrated that the results of A. K. Walter's tests are reasonably correct.

To apply high suction it is necessary that the sintering apparatus be air-tight from the top surface of the charge to the fan exhauster.[2] Exhaust fans of superior design are required for this type of work, for these fans operate at high speeds and must be thoroughly protected from the heavy dust conditions that they encounter. Some very good fans are available for this type of duty, however.

4. High Thermal Efficiency in Sintering

Sintering is a highly efficient thermal process when properly conducted. To obtain the highest fuel economy it is necessary to properly arrange the charge undergoing sintering, and this depends on the discovery that, while heating a charge with high suction, a sintering temperature once properly initiated by means of a thin top layer containing the necessary fuel can be maintained and propogated through a charge containing much less fuel than that necessary to start or initiate that sintering temperature.[2] Charges are prepared in varying depths, and they may contain approximately 3 per cent of coke (excluding flue dust) in a layer about 14 inches thick. A top layer which contains approximately 6 per cent of coke, and which is about 1 1/2 inches deep, is placed on top of the charge layer. The igniting flame is applied instantaneously to every square inch of the top surface and is maintained for 30 seconds to 1 minute.

It has been suggested that if a flame of sufficient intensity were applied to ignite the sintering charge that the extra coke used to help start the ignition would be unnecessary. (This is not the current practice.) I believe that the answer to this question is that too intense an ignition charge causes drying out of the charge just as does too slow a sintering rate, and that the results of both are the same; namely, a slower sintering rate and decreased sinter output.

After ignition, the sintering zone moved downward in a plane whose area is the size of the entire sintering unit and parallel to the grate surface. This sintering zone, where the actual sintering is occurring, is very thin; it is probably not more than 1/16 inch in thickness. Immediately after ignition this zone passes beneath the surface of the charge, and after that the incoming air, before reaching the sintering zone, must pass through incadescent sinter, so that by the time the air reaches the sintering zone it is highly heated.[2] On the other side of the sintering zone the highly heated products of combustion are passing through the part of the charge immediately ahead of the sinter zone. Therefore, there exists not only preheated air, but also a highly preheated charge, thus producing excellent conditions for economical combustion.[2]

By reducing the fuel content of the main charge below that ordinarily used, the sintering action is speeded up so that the heat required for sintering does not remain long enough in any locality in the charge to cause the formation of iron silicates.

Proper ignition of the charge is important, and the time required to accomplish this usually does not exceed 30 seconds. Every square inch of the charge surface must be fully and evenly ignited.[2] Long ignition periods dry out the charge, produce uneven sinter, and may even produce considerable amounts of undesirable Fayalite (Fe_2SiO_4).[23] A clean, high-temperature and highly oxidizing flame gives the best results; for this reason high-grade fuels such as oil, natural gas, or coke-oven gas are preferred over blast-furnace or producer gas.[2, 23]

The grate receives severe punishment in any down-draft sintering apparatus. It should be self-cleaning and should have an opening of approximately 20 per cent of the grate area. The amount of grate opening is a function of the particle size and character of the material being sintered, the finer ores requiring less grate opening area if they tend to run.[2, 23] It is often necessary to place a layer of coarser material over the grates to prevent the loss of too much matter into the suction pipe. Also, if a layer of ore containing very little or no fuel is placed upon the grates, it will prevent the formation of a highly fused sinter which frequently tends to adhere to the grates.[2]

Sinter should be air cooled, for if it is water cooled it tends to be very brittle and breaks readily during handling and shipping.[23] Air-cooled sinter is much stronger than the water-cooled variety, and sinter containing lime should not be moistened.

5. Sulphur Elimination

The elimination of sulphur is an important consideration in the treatment of certain sulphur-bearing iron ores, and its content should be lowered to 0.10 per cent or less for blast furnace use. Sulphur burns quite readily, so it is necessary to reduce the carbon content of a sulphur-bearing ore to a minimum so that the heat released by the combined burning of the carbon and the sulphur is just high enough to produce a sintering temperature. If more carbon is present, the oxygen combines with the ca bon in preference to the sulphur, thus fusing some of the sulphur compounds from which it is extremely difficult to remove the sulphur. Fine crushing also favorably affects sulphur elimination.[2]

If the sulphur exists as sulphides in the ore, it replaces a certain amount of carbonous fuel required for sintering; sulphur will usually replace its equivalent weight of carbon as a sintering fuel; however, this is not true if the sulphur exists as sulphates. The lower requirement of carbon sintering fuel for a sulphide-bearing ore renders it more attractive from the standpoint of cost, since fuel is the principal cost item in sintering ores where such fuel must be purchased or supplied extraneously.

6. Physical Structure of the Sinter

It has been suggested by Greenawalt[7] and Agnew[23] that lime be added to a sintering charge to produce a self-fluxing sinter and at the same time form a more reducible sinter by preventing the formation of iron silicates. The method by which lime can prevent iron-silicate formation will now be briefly discussed.

A silicate is a compound of silica and some other element or elements. In the presence of a fusing temperature chemical law compels the acid silica to seek a union with some basic element or elements. In the ferrous materials those basic elements are usually aluminum oxide, calcium oxide, magnesium oxide, manganese, and iron. Since the sintering operation is a fusion, the formation of silicates is inevitable and cannot be controlled by the sintering machine operator once the process is started. All of the silica in the charge will be converted to silicate, and if the other basic elements in the charge do not satisfy the silica percentage the excess silica will combine with iron to form iron silicate.

The addition of $CaCO_3$ to such a charge would prevent the iron silicate formation by forming Ca_2SiO_4, and at the same time a self-fluxing sinter would be formed. However, there are disadvantages of having a sinter containing no iron silicate.

The structural strengthening effect of the iron silicate compound increases as the percentage of iron in the compound increases, and if there is not enough of the other base elements present in the mix to balance the silica percnetage, the excess silica will satisfy itself with iron alone and the silica Fayalite (Fe_2SiO_4) will form. Fayalite has exceptional structural strengthening effect upon sinter, and if present in large percentage the natural friability of the sinter is reduced to a minimum.[23] If suitable materials are available, a silica content of approximately 5 to 6 per cent (natural) balanced with base elements other than iron in the ratio of 1.5 to 1.0 is a good standard to approach.[23] Actual practice seems to indicate that there is a limit to the benefits of having the base elements approach a balance with the silica percentage, but the conclusions on this matter are not too definite as yet. Some iron silicates are necessary for sinter structural strength, so the silicate-formation problem is a weighty one.

A method was developed to determine the amount of iron silicate in sinter by Joseph.[7] He shows that this constituent of sinter increases sharply from 8 to 10 per cent silica, and above this range enough is likely to be present to retard reduction of the iron oxides appreciably. If the silica exceeds 10 per cent, significant amounts of iron will exist as iron silicate which probably reaches the hearth unreduced. Fayalite forms a protective coating about the magnetite and hematite grains, and it is reduced only with great difficulty.[7]

The silica content of the sintering mixture should be considered in sintering practice. Strong, dense blocky sinters made from siliceous material are reduced slowly because of the combined effects of the physical and chemical properties.[7]

The time required to reduce coarse particles of ore increases directly with the diameter of the pieces, but with porous sinters the solid continuous sections may be as thick in 3/4 inch pieces as in 1 1/2 inch pieces.[7] Large pieces of hard, dense sinters appear to be objectionable, particularly if produced from siliceous material.

The permeability of dense iron ores, mined in coarse sizes, is a good criterion for determining the size to which the ore should be crushed; however, permeability measurements on a number of ores from various districts vary widely. The chemical properties of the iron ore minerals are relatively unimportant in comparison with their physical characteristics.[7]

Professor Kerr of Yale[2] showed by microscopic examination that, contrary to popular belief, the iron oxide in the sinter is not nearly all magnetite. Rather, his studies showed that all of the hematite present in the original ore had been changed partly into magnetite and partly into a recrystallized form of hematite.

The principal non-metallic constituents of the sinter produced during the sintering operation is glass. The fine quartz particles of the original ore, together with a considerable portion of the calcite, form glass.[2]

VII. SOME OPERATIONAL FEATURES OF A MODERN SINTERING PLANT[20]

The newly completed sintering plant of the Wheeling Steel Corporation, Steubenville, Ohio, will serve as an example of a modern sintering plant.

This plant extends in a straight line almost 700 feet from the track-hopper station on one end to the centrifugal dust catcher on the other end, and the sintering operation begins at the hopper station and is concluded at the other end.

Stockpile iron ore which is to be sintered is moved from the stockpile by transfer cars or side dump cars direct to two bins at the track-hopper station. Two revolving table feeders deliver 480 tons of ore per hour from the bins on to a 30-inch belt conveyor, and this belt conveyor dumps its load into a hopper atop the screening station. (The ore is weighed on a belt scale while on the conveyor.) At the top of the screening station the ore is discharged on to a 5 by 12 inch double-deck vibrating screen with the top deck of 1-inch mesh and the bottom deck of 1/2-inch mesh screen. The oversize products from the top and bottom decks join and are discharged on to a 24-inch reversible conveyor which transfers oversized material either into the ore yard pit or into railroad cars for blast furnace use. Undersized materials from the screens falls on to a 30-inch conveyor belt which delivers it to a 30-inch shuttle conveyor serving all of the storage bins. This arrangement keeps raw material handling independent of sintering plant operation, and if it fails, it has no effect on the sintering plant production.

A belt scale weighs all of the fines in transit from the screening station to the sintering plant storage bins.

Seven concrete storage bins, with 5560 cubic feet capacity apiece, serve the sintering plant. Five of the bins are used for screened ore fines storage, and two bins are used for storing flue dust and coke breeze. Provision has been made for the handling of flue dust and coke breeze at the track-hopper station if necessary. Each bin is equipped with a 6-1/2 feet revolving table feeder which is controlled from the operating floor.

The sintering-plant building is located beyond the storage bin building, and the operating floor is on the same level as that of the storage building; this facilitates crane work in both places. The sintering-plant building is of concrete construction, and no glass has been used in the entire plant; many technical devices have been used to provide constant ventilation and a clean plant.

The sintering machine (continuous) is 72 inches wide by 89 feet long, and it is built with a side discharge so that the product can be directed into the yard pit or into railroad cars; this gives either a water-cooled or an air-cooled sinter. This machine produces 75 tons of sinter per hour. A fan rated at 126,000 cubic feet per minute provides ample wind-box suction, and two centrifugal dust catchers remove particles of dust from the combustion products before they enter the fan, thus helping to preserve the fan blades.

Raw materials from the storage bins drop on to a 24-inch main-feed conveyor belt and are delivered directly to a hopper serving the pug mills on the main operating floor of the sintering plant. (A pug mill is a mixer which mixes the constituents of the sintering charge with water just prior to sintering.) Two pug mills, one acting as a spare, have been installed to insure continuous service.

The main feed conveyor immediately after it leaves the storage bins receives hot returned fines and fine flue dust from the sintering machine discharge screenings; this hot material is fed on top of the cold bin material, and therfore it does not burn the conveyor belt.

The ignition furnace has three independently operated 84-inch arches; each of which is independently supported from above; this allows removal of the ignition units separately. Three burners are positioned on each side of the furnace at varying inclinations, each bank being staggered so as to not conflict with the other. This arrangement allows the flame to impinge upon the bed at different points, and with good results.

The efficient design of this plant was proved when within three hours after it started its first operation it was up to its rated capacity. This plant was designed by A. G. McKee and Company, Cleveland, Ohio.

VIII. BLAST FURNACE PRODUCTION AS INFLUENCED BY THE SINTER CONTENT OF THE FURNACE BURDEN

It is the consensus of blast furnace operators that the addition of sinter to the blast furnace burden will increase blast furnace output. However, it is erroneous to assume that the addition of sinter to <u>any</u> blast furnace burden will increase the output of that furnace.[9, 10, 20, 21] The physical character of the burden into which the sinter is introduced and the physical nature of the sinter, along with relative reducibility of the ore and the sinter substituted for the ore, are the prime factors to be considered in sintering practice. Since these factors vary widely at each company which operates blast furnaces, it is impossible to make all-inclusive conclusions as to the effect of the increased sinter content in the blast-furnace burden upon the furnace output. Since modern furnace practice is tending toward increased sinter use in the burden, an example of benefits derived from such a practice will be covered in the succeeding paragraph.

Engineers and operators of Republic Steel Corporation have recently completed a series of experiments on increasing pig iron output of both large and small blast furnaces by increasing the percentage of sinter used in the furnace burden. Test runs were made over a period of four years at their Cleveland and Youngstown plants. This company believes that most of the northern blast furnaces in the country can duplicate their results.[18]

In brief, Republic has found that by increasing the percentage of sinter in the furnace burden to as much as 40 or 45 per cent, the output of iron as shown by different furnaces can be increased anywhere from 10 per cent to 19 per cent. Reduced to specific terms it can be said that a blast furnace rated at 1000 gross tons per day, consuming only its normal amount of coke, and with scrap being held practically constant can produce about 140 more tons of pig iron per day with 45 per cent sinter in the burden.[18]

Few experiments were tried using over 45 per cent sinter burden, but results from a furnace using a 100 per cent sinter burden indicate that beyond 45 per cent there is little further advantage other than the increased iron units in the sinter.[18]

<u>Effect of Sinter on Blast Furnace Operations</u>

	Consumption %		Production %	
Per Cent Sinter	Coke Rate	Flux Rate	Flue Dust	Daily Iron
0	100.0	100.0	100.0	100.0
10	94.2	92.9	79.2	103.2
20	90.4	87.4	66.0	106.3
30	87.2	82.7	56.0	109.5
40	84.8	79.4	49.2	112.5
45	83.9	78.1	46.4	114.2

The table of data summarizes the effect of sinter on blast furnace burdens,[18] the 100 per cent figures representing data obtained from the operation of a furnace using sinter-free Lack Superior ore burden.

These data, which are a composite average of the several furnaces under test, show a marked drop in coke consumption (over 15 per cent); a substantial decrease in the amount of fluxing material required (over 20 per cent); a drop in the amount of flue dust produced of nearly 50 per cent, and an increased pig iron production of 10 to 19 per cent. This article did not list the cost of sintering the charge, nor the amount by which the profit from the increased tonnage exceeded the sintering costs; also, the reason for the decrease in flux consumption was not stated. However, I assume that a profit was experienced by this company or else they would not state the results of their work so positively.

These data indicate that a program of increasing blast furnace burdens from an average use of 10 or 15 per cent sinter to upwards of 45 per cent should be highly desirable to blast furnace operators. This, and other similar tests,[14, 13, 7] indicate that there is but little advantage to use over 50 per cent sinter in the blast furnace burden other than the increased iron units in the sinter, because the charge becomes so open that intimate gas-solid contact is not maintained.

A program to increase the use of sinter would necessarily involve the construction of considerable new sintering capacity throughout the country. The time factor, as compared with the time required to build new blast furnaces is markedly in favor of such a program. It is possible to build a new sintering plant of, say, 1200 tons' capacity per day, in 6 months or less. Only about five hundred tons of steel are required in the plant construction, and the plant with all equipment ready to run can be constructed for $600,000; this is about 5 per cent of the cost of a modern blast furnace. Actually the difference in expenditures involved is even more than this, since with a new blast furnace there is additional coke-oven capacity required which is not the case with a new sintering plant.[18]

IX. CONCLUSION

In recent years several sintering plants have been built in connection with ore crushing, sizing, screening, and blending plants.[12] The ore is usually crushed and screened into three sizes, the two larger sizes going to the blast furnace, while the minus 3/8-inch size goes to the sintering plant where it is sintered with flue dust, roll scale, and other available iron-bearing materials.

It is to be expected that many more of this type of plant will be built as it becomes more and more necessary for this country to beneficiate its iron ores. This type of plant could be especially applicable in the Minnesota and Alabama iron-mining districts if cheap enough fuel is obtainable.

An increased use of Eastern magnetic iron ores would also increase the use of sintering, for sintering is the major operation of the magnetic ore concentration plants.[10] About 29 per cent of the sinter producing capacity of the United States is located in these plants; magnetic ores must be crushed and rolled to a very fine size to effect a magnetic separation; therefore, it is necessary to sinter the magnetic fines to make them suitable for blast furnace use.

Thus, the future for sintering appears to be good in this country.

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